B003

Enhanced Wavefield Separation of OBS Data

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SUMMARY

In ocean-bottom seismic (OBS) data processing, wavefield separation results are sometimes affected by high levels of noise on the vertical component Z, while the pressure component P is in general of good quality. Nonetheless, Z is needed to achieve complete pre-stack wavefield separation and also to drive processes such as mirror imaging and up-down deconvolution. To address the problem of noise on Z affecting wavefield separation results, we propose a new method which first estimates a multiple model from the downgoing wavefield in a least-squares fashion. Next, this multiple model is used as a measure of seismic signal coherency to calculate an enhanced upgoing wavefield with minimal noise degradation. We show the benefits of this new method on a real data example from the Caspian Sea.

Introduction

In ocean bottom acquisition, a hydrophone and a three component geophone are embedded in an ocean bottom cable (OBC) or in individual nodes (OBS) to record pressure and particle velocity data. This allows recording of the full elastic wavefield and its separation into upgoing and downgoing parts (see for example Barr and Sanders, 1989). Wavefield separation is the basis for the "*PZ summation*" data processing procedure, commonly used to attenuate all downgoing multiple energy at the receiver side.

Wavefield separation can be thought of as occurring either infinitesimally below or infinitesimally above the seabed (Amundsen, 1993; Schalkwijk et al., 1999; Osen et al., 1999). Figure 1 shows a schematic diagram for upgoing and downgoing events below and above the seabed reflector. A summary of the elements of upgoing and downgoing wavefields at these separation levels is shown in Table 1. It should be noted that efficient and accurate wavefield separation is often a requirement for successful further processing. Wavefield separation is typically followed by either additional multiple attenuation or by up-down deconvolution, and finally by conventional or mirror imaging. Among these additional processing steps, up-down deconvolution shows the highest sensitivity to wavefield separation results. Demultiple and imaging also benefit from accurate separation.

Vertical component data from ocean bottom recordings are often corrupted by high level of noise compared to the pressure component. When applying standard separation techniques, this noise ends up being propagated to the upgoing and downgoing wavefields and can be so severe that the separation results become almost unusable. Often referred as "Vz noise" or shear wave noise in the literature (Paffenholz et al., 2006), this noise is coherent on common receiver gathers but random in common shot gathers. It exhibits a converted wave moveout and its strength depends strongly on the coupling and the ocean bottom conditions. Previous attempts to eliminate this noise include velocity filtering (Shatilo et al, 2004) and coherent-energy decomposition between hydrophone and geophone (Craft, 2008).

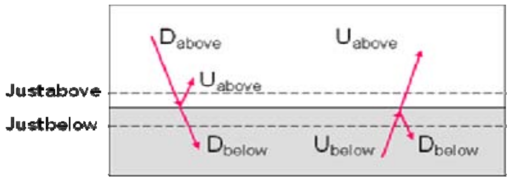


Figure 1 *Schematic diagram for wavefield separation above or below the seabed.*

$\mathbf{U_{above}}$: primaries and multiples
$\mathbf{D_{above}}$: receiver side multiples
$\mathbf{U_{below}}$: primaries and source side multiples
$\mathbf{D_{below}}$: primaries and multiples

Table 1 *Different type of energy in the upgoing and downgoing wavefields after separation above or below the seabed.*

Method

Conventional wavefield separation combines *P* and *Z* to deliver *U* and *D*. Our enhanced separation algorithm makes use of an additional input, a multiple model *M*. Such a multiple model can be obtained in a variety of ways, including for example wave-equation extrapolation of a reflectivity estimate or an initial wavefield separation result. The latter is based on the fact that the downgoing wavefield just above the seabed contains multiple energy only. In the remainder of this paper, this downgoing wavefield is used as model, after a simple direct-arrival mute. Regardless of the model used however, noise present on *Z* affects *M*.

Once a multiple model *M* is available and provided that the pressure component is characterized by a good *SNR*, a first step of the proposed method is a least-squares adaptive subtraction of the model from *P*. Note that Z could be used for this purpose in cases where its SNR is higher than that of *P*. At this stage, priority is given to noise removal rather than signal preservation. The result is an initial estimate of U, U':

$$U' = \mathbf{min}_f \left\| P - f * D \right\|^2 \quad , \tag{1}$$

where *f* is filter or set of filters that provides the desired noise attenuation. U' is free of noise, but suffers from primary loss. In the second and final step of the proposed method, this estimated upgoing wavefield drives an *f-k*, *f-x* or *f-p* amplitude-independent coherency estimate *C*. The choice of domain depends on signal and noise characteristics and is meant to facilitate signal-noise separation. Several factors can influence this choice, such as the presence of aliasing and type of noise move-out. This coherency estimate is then used to effectively reject noise on *Z* during wavefield separation and obtain enhanced *U* and *D* wavefields, U_E and D_E. Schematically, in the case of U_E for example,

$$U_E = \begin{cases} P+Z, C \geq c_T \\ 0, \quad\quad C \leq c_T \end{cases}, \tag{2}$$

where c_T is an adaptively determined coherency threshold. We name the method discussed above *enhanced wavefield separation*. While it would indeed be possible to simply use *P* as a coherency estimate guide, we find that since *P* contains both primary and multiple energy it is not as effective as U'.

Real Data Example

We apply the proposed method to a 2D line from a 3D Caspian Sea OBC survey. Figure 2 shows stack sections of the *P* and *Z* components. The SNR of *Z* is significantly lower than that of *P*. Although noise attenuation was part of the processing sequence, extreme care was taken in not perturbing primary amplitudes. Stronger noise attenuation was therefore rejected in favour of signal preservation. The processing steps applied were:

- *f-x* noise attenuation of both *P* and *Z*
- *PZ* calibration based on direct arrival matching
- Trace interpolation

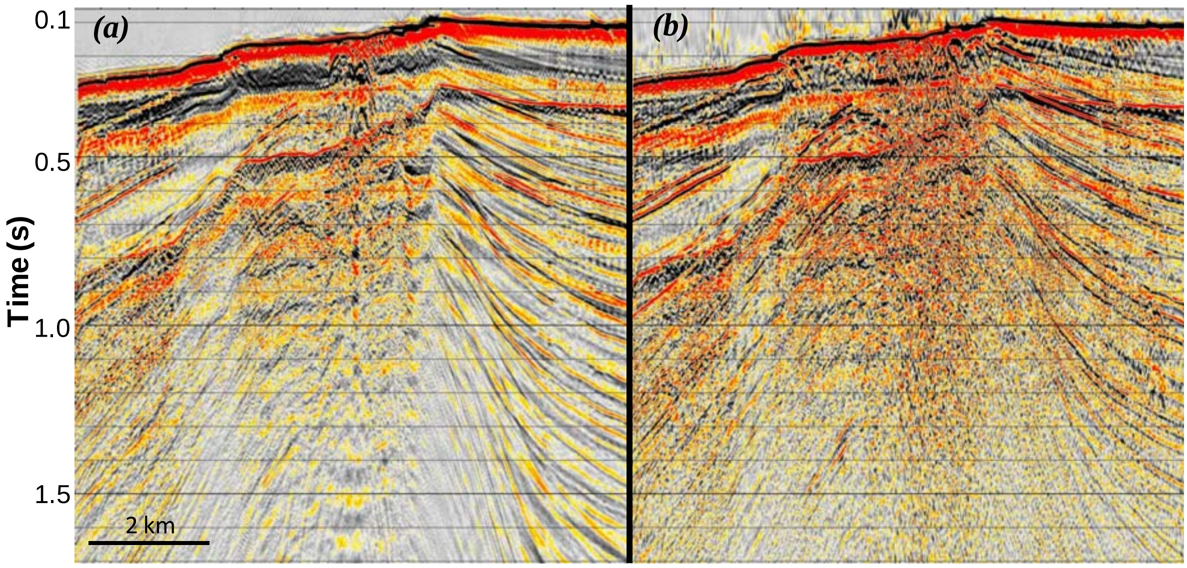


Figure 2 a) *P component stack* ***b)*** *Z component stack. The noise level is clearly higher on Z.*

Figure 3 shows receiver gathers of *P*, *Z* and upgoing wavefields. 2D wavefield separation was applied pre-stack and resulted in the upgoing wavefield in Figure 3c. The high level of noise on Z obscures shallow events in this conventional upgoing gather. Enhanced wavefield separation restores the signal quality of *P* while simultaneously eliminating noise and preserving separation accuracy (Figure 3d). In this case, we performed the coherency estimate in the *f-k* domain. NMO stacks of the conventional downgoing wavefield above the seabed and of the upgoing below the seabed shown in Figure 4a and 4b. The uncorrelation of Figure 4a and 4b demonstrates the high quality of the achieved separation. Figure 4c shows the corresponding stack of the enhanced upgoing. Figure 5 shows a close-up of the upgoing wavefield after pre-stack time migration with and without applying the proposed technique, as well as a difference section. We can observe that this technique improves the quality of the image by effectively attenuating the noise and improving the signal continuity even after migration.

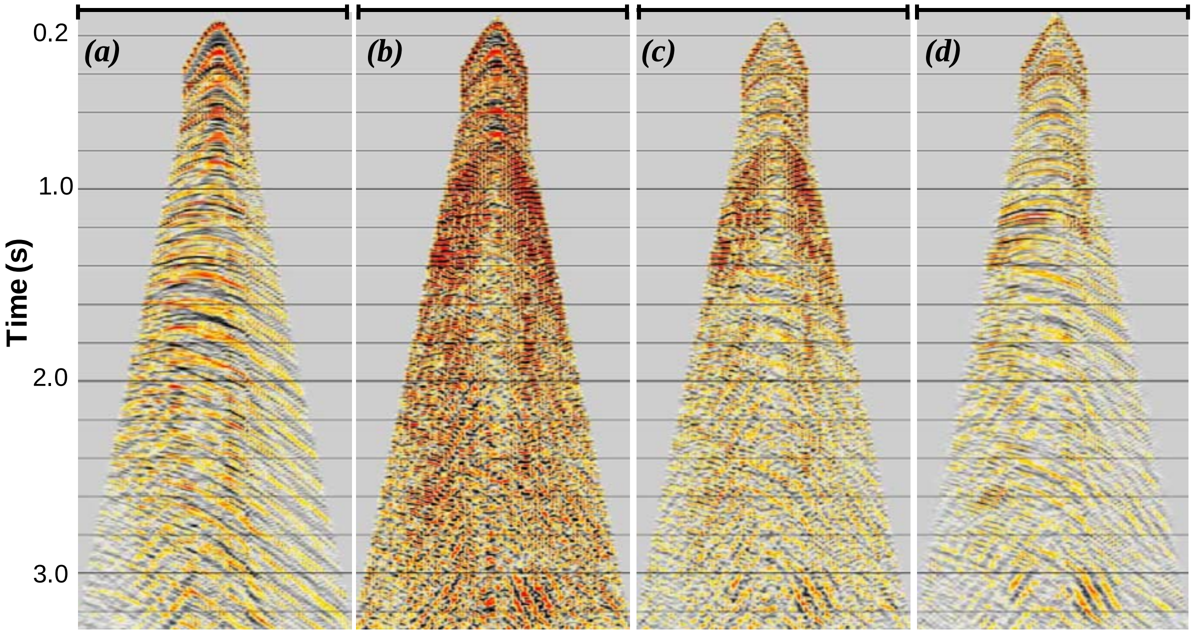


Figure 3 *An example receiver gather display of* ***a)*** *P component* ***b)*** *Z component* ***c)*** *upgoing wavefield* ***d)*** *enhanced upgoing wavefield obtained using our proposed method. Offset range: ± 4500m.*

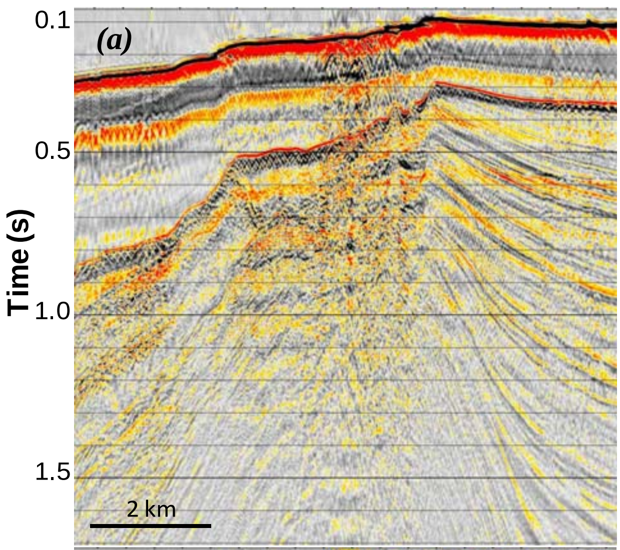
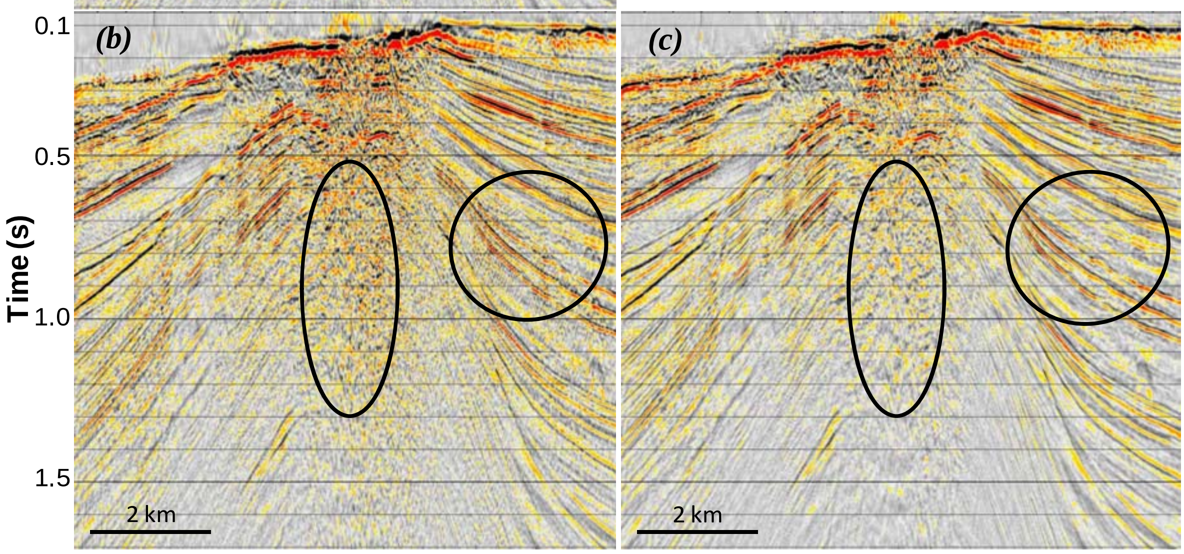


Figure 4 *Downgoing wavefield just above the seabed (**a**), and upgoing wavefield just below the seabed (**b**). The former is often a useful quality-control as it should only contain multiple energy and therefore be uncorrelated from the upgoing wavefield. The latter is equivalent to a conventional PZ summation result. Notice how the noise originally present on Z now degrades both upgoing and downgoing wavefields.* ***c)*** *Enhanced upgoing wavefield. Note the improvement in the coherency of the events and the removal of noise, for example in the highlighted areas.*



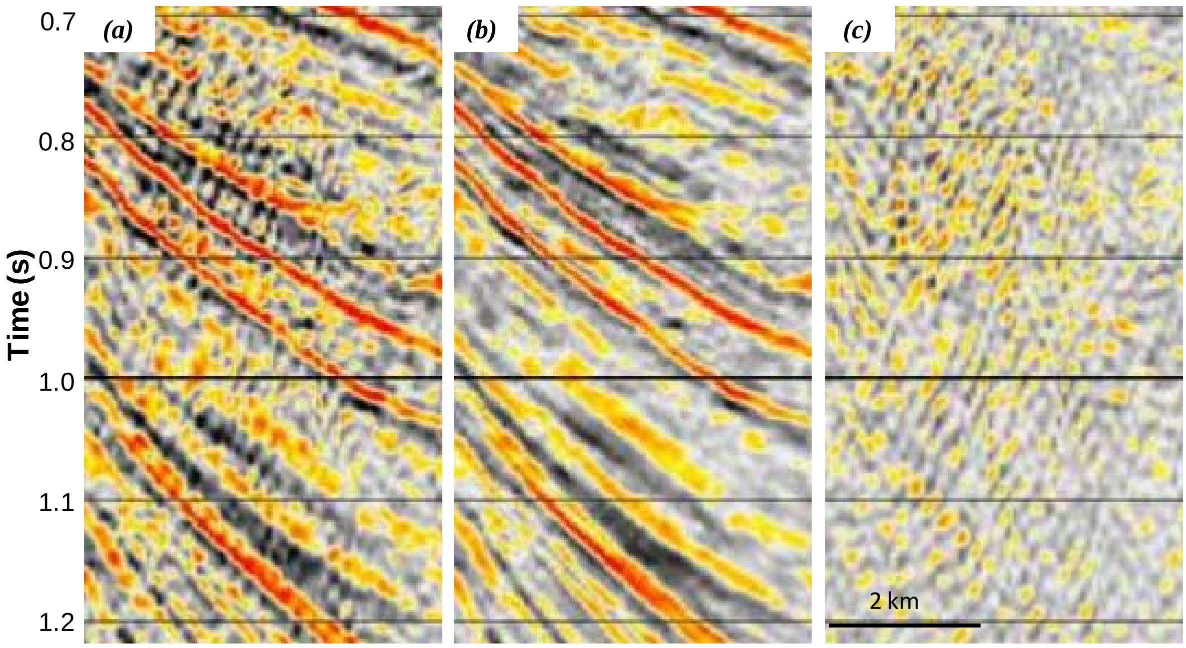


***Figure 5** a close-up display of the **a)** conventional and **b)** enhanced upgoing wavefield after pre-stack time migration. **c)** The difference section demonstrates the effective power of this technique in removing noise.*

Conclusions

We discuss a new technology to improve wavefield separation quality, which is sometimes affected by the presence of high amplitude noise in the *Z* component. Application of the method to an OBC dataset from the Caspian Sea delivers an upgoing wavefield with excellent signal preservation and strong noise attenuation. This technology can also be extended to the calculation of downgoing wavefields.

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